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Simulated surrogate measures to assess the effectiveness of countermeasures at signalized intersections

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Abstract

The traditional method for assessing safety conditions at signalized intersections depends on historical crash data. Difficulty and long waits for data collection as well as lack of reliability, represent some limitations. As a result of safety evaluation using traditional methods, countermeasures may be proposed to improve the degree of safety. This paper aims to assess the effectiveness of countermeasures at signalized intersections using micro-simulation model (VISSM10) software and the Surrogate Safety Assessment Model (SSAM) to deal with traffic conflicts as surrogate measures rather than crash data. The study relied on VISSIM10 to create a trajectory file as input of SSAM to conduct a traffic safety assessment using traffic conflict indicators of time to collision (TTC). Four four-legged signalized intersections in the city of Diwaniya are chosen to assess safety and then propose appropriate countermeasures. Different countermeasures are tested through simulation to estimate their effectiveness using two measures: the increase in time to collision and the percentage reduction in traffic conflicts. The results showed that model calibration reduced the mean absolute error of prevention (MAPE) and improved the fit between both the actual conflicts and simulated conflicts. A validation simulation has been performed compared with the observed conflict. According to the linear regression the number that simulated conflicts which highly related to the number of actual conflicts. Additionally, R^2 can be described by the difference in simulated conflicts. Results go with effectiveness based on crash data and promising for unknown ones.

Keywords: Countermeasures, SSAM, VISSIM, Conflicts, Crashes

1. Introduction

Traffic accidents frequently happen at intersections because of many conflicts caused by users traveling through, the safety of transportation is a top priority for road engineers. Understanding intersection collisions' causes and potential solutions is a top priority while researching them. Throughout their cycle life, intersections should be routinely checked and reviewed. To improve the safety conditions for the road network, safety practitioners focused their efforts and resources on researching and analyzing intersection safety in different countries. The majority of current studies on traffic safety focus on the statistical evaluation of collision data. As a result of the modeling attempts' effectiveness and the requirement for more in-depth understanding.

Although crash data are significant, there are some limits associated with accident data and corresponding modeling techniques, like underreporting, lack of heterogeneity, and an insufficient sample size [1]. The investigation of alternative safety measures that don't rely on the occurrence of a crash, including the occurrence and character of traffic conflicts, has grown as a result of the limits of collision data and collision-based methodologies over time. Because of the enormous amounts of vehicle information in real-time that are probably to be readily available, these alternative safety measures often referred to as collision surrogates in the literature will probably play a significant part in road safety analyses in the upcoming connected and autonomous vehicle age [2]. Human error is the primary cause of traffic accidents [3]. Active vehicle safety measures have recently been designed to lower the chance of collision as a result of rapid developments in communication technology, computer power, and data-collecting technology. The identification of traffic conflicts and the evaluation of traffic safety both benefit from the use of surrogate measures of safety (SMoS) [4].

2. Material and methods

2.1. Traffic safety in Iraq

Traffic accident injuries are of great danger and are comparable to the present terrorist happenings, as they are a scourge that constitutes an obsession and worry to all parts of society and have become one of the issues that deplete material resources, social issues, and loss of human power that have an impact on the aspects of life where the human energies that affect the elements of life in which the human element is the basis of society. Iraq is witnessing many traffic crashes and a large number of deaths and injuries, which have reached high numbers over the past ten years. This is confirmed by the annual reports issued by the Central Statistical Organization (CSO) of the Iraqi Ministry of Planning, in cooperation with the Minister of Interior / Criminal Statistics Directorate. The following are the main indicators of traffic safety for the year 2020, according to CSO in the governorates of Iraq except for the Kurdistan region.

2.2. Statistical indicators of crashes in Iraq

- There were 8186 traffic accidents recorded, of which 2152 were fatal accidents and 6028 were non-fatal accidents.
- Collision accidents noted the peak percentage in 2020, reaching 4524 collisions which is 55.3% of the total number of crashes (8186). There were 2793 hit crashes, which amounts to a total of 34.1%. 773 turnover accidents (9.4%) and 96 other crashes (1.2%) make up the rest.

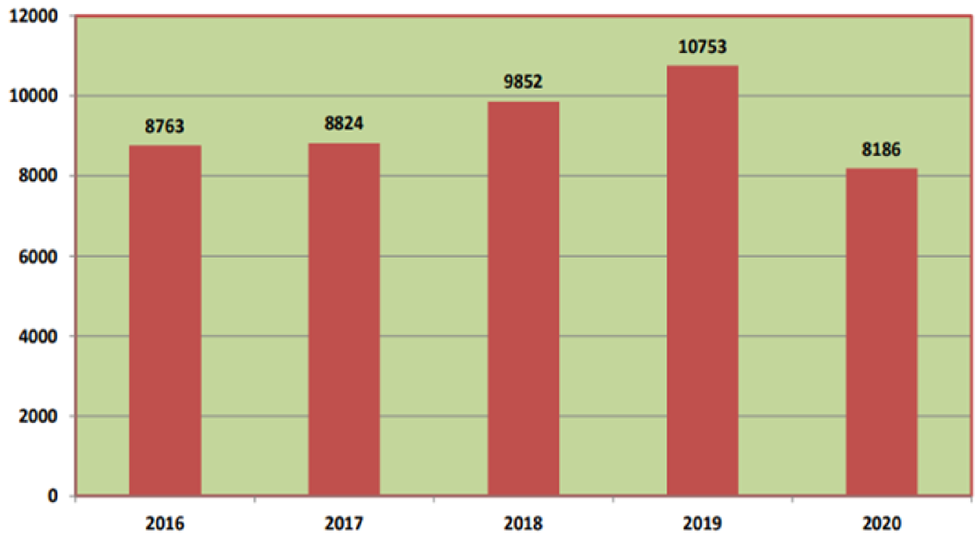


Figure 1. Number of traffic accidents for the 2016-2020 period

- The sum of traffic accidents in Diwaniya reached 1127 crashes which were distributed to five districts as shown in Table 1.

Table 1. Number of crashes in each district

Governorate	Aiqada	Injuries	Deaths	No. of accidents
	Diwaniya	360	42	320
Al-Qadysia	Afak	149	24	107
	Al-Shamia	109	17	96
	Al-Hamza	63	24	64
	Total	681	107	587

2.3. Surrogate safety measures (SSMs) in safety assessment

SSM is the method of safety measure based on observed non-crashed events, therefore the term "surrogate" represents a measure that does not rely on historical collision data but relies on unsafe events (non-accident events) in the traffic process to be an accompaniment or an alternative to collision record-based evaluates [5]. SSMs are any events that can be correlated with crashes. Because these methods use events that occur at a much greater frequency than crash rates, it is possible to evaluate the safety of a given location without waiting for a large number of crashes to occur so road safety analysts can profit from dependable analysis measures that utilize observable non-crash traffic events [6]. SSM as an alternative safety measure offers the opportunity to evaluate traffic safety when crash counts are not obtainable; the additional important attraction of SSMs is that saving time since there is no need to wait for adequate crashes to appear before problems are known, and the treatment implemented.

2.4. Micro-simulation technique

The technique of simulation modeling has become utilized with greater popularity and is proving to be effective for resolving a variety of dynamic issues, especially those caused by difficult-to-explain complex stages. These processes are often identified by the complex interactions of numerous system components or entities. In particular, simulation models are software-based mathematical/logical simulations of actual systems that are run experimentally on digital computers. The fact that these models are by no means exhaustive is the main benefit. The goal of a model used for simulation is to depict a dynamic representation of a real-world traffic situation [7]. A microscopic model of traffic flow simulates interactions between drivers on the highway in order to study the movement of traffic. Gettman and Head first improved an advanced method termed Surrogate Safety Assessment Models (SSAM) and studied the possibility of obtaining SSM from obtainable simulation models, The SSAM is a software developed by FHWA to estimate surrogate safety measures based on traffic simulation modeling [7]. A traffic conflict happens when two vehicles approach each other so that if no evasive action is taken during their original trajectories, a collision occurs. SSAM reads trajectory files generated by microscopic simulation programs to recognize the number and type of traffic conflicts between vehicles during the simulation period. The vehicle trajectory files can be obtained from microscopic traffic simulation softwares such as AIMSUN, VISSIM, PARAMICS, and TEXAS.

2.5. PTV VISSIM

- According to PTV Group, the industry-standard microscopic traffic and transportation planning tool that relies on simulation and modeling is PTV VISSIM technology. The following applications for this program exist.
- The decision-making procedure for developing a sustainable transportation system is aided by transportation flow simulation software.
- Advanced Traffic Management Systems – software helps to reduce the negative impacts of transport systems.
- Multimodal Systems – software helps to study all transport modes including pedestrians.

- Autonomous Vehicles and New Mobility – software helps to model and simulate the impacts of autonomous driving.
- Virtual Reality Traffic Simulation – software helps to create microscopic traffic simulations.

2.6. Surrogate safety assessment model (SSAM)

A software program, the Surrogate Safety Assessment Model (SSAM) was created to carry out statistical evaluation on vehicle trajectory data produced by microscopic traffic simulation techniques. For each conflict found in the trajectory data, the software calculates a number of surrogate safeties before computing summaries (mean, max, etc.) for each one of the surrogate safety measures [8]. The four kinds of conflicts recognized by SSAM are crossing (angle), lane-changing, rear-end, and unclassified. On the basis of the conflict aspect, link, and lane data, the kind of conflict is chosen. Based on the angle at which two cars approach a potential collision location, a conflict angle for each couple of vehicles is determined. SSAM estimates a total of corresponding surrogate safety measures (TTC, PET, etc.), as well as their summary (mean, max, and variance).

2.7. Using VISSIM and SSAM in combination

VISSIM and SSAM software were used and showed the system configurations can avoid the accidents, it was possible to show that on the one hand, a combination of microscopic traffic flow simulation and accident simulation is not only technically feasible but can also provide a large number of unique traffic scenarios as well as valuable additional information, e.g., on environmental traffic that is indirectly involved in conflicts. It was shown that these secondary traffic participants have a considerable influence on the visibility of objects [9].

The micro-simulation environment was used to predict the conflict between a vehicle and another vehicle, as well as between vehicles and pedestrians at signalized intersections in Doha, Qatar. The VISSIM modeling tool was used to simulate car and pedestrian trajectories at the intersections under study. The simulated data was then analyzed using (SSAM) to find conflicts within the study zones. The findings showed that conflict may be inferred from the data. Additionally, the micro-simulation method may be utilized to predict probable conflicts throughout scenario evaluation, and the results can be recognized to evaluate how the geometric improvements affect the likelihood of disputes.

Some work includes a simulation-based evaluation of traffic safety in two roundabouts [10]. The study compared the safety of a basic turbo-roundabout that was suggested with a two-lane roundabout that was already in place for the same intersection in order to determine which was safer. It used (VISSIM) and SSAM programs to find six substitute safety measures and compare the results. The total number of conflicts was found to be 72% lower at the turbo-roundabout, and it was discovered that, in contrast to the roundabout, traffic conflicts at the turbo-roundabout tend to cluster together.

Safety evaluation was examined utilizing the VISSIM simulation model and the surrogate safety assessment model SSAM at the offset diamond interchange (ODI) compared to the conventional interchange due to its failure. According to the findings, the ODI demonstrated the potential to be a viable alternative and an efficient design.

3. Safety countermeasures

Safety countermeasures are activities done to enhance transportation safety and then reduce the number of injuries and fatalities. Safety countermeasures may consist of geometric design and systemic safety. Programmatic countermeasures are used to attack systemic safety problems that prevail throughout the highway system. These measures generally involve education and/or control of drivers, vehicles, or highway design features. The selected intersections suffer from large turn volume, absence of left-turn phase, inadequate signal timing, large total intersection volume, large turn volume, and other problems that increase risks, collisions, and decrease safety.

In this paper, many countermeasures are used to improve safety at intersections according to the literature review which summarized in Table 2 countermeasures and crash reduction percentage of traffic conflicts to improve traffic safety. These countermeasures are summarized as follows:

- Increase the width of lanes
- Increase the number of lanes
- Improved traffic signal
- Add left turn phasing
- Cancel U-turn

3.1. Countermeasure selection

Choosing countermeasures for a location involves three basic steps:

1. Define the elements that affect the reasons for accidents at the study location.
2. Identify preventative steps that might address the contributing causes, and
3. If possible, perform a cost-benefit analysis in order to determine the preferable course of action.

Any general or site-specific safety study has as its objective the creation of programmatic or site-specific modifications to lessen the conditions that cause these accidents. However, every case has specific peculiarities that must be carefully examined. National, regional, and local statistics must be taken into account during program formulation, and comprehensive accident and condition data is needed for site mediation. In order to address systemic safety issues that exist throughout the entire roadway system, programmatic countermeasures are implemented. These actions typically entail control and/or education of divers, vehicles, or highway design features.

Table 2. Countermeasures to reduce the percentage of traffic accidents to improve traffic safety

Reduction in traffic accidents %	Type of countermeasures
75	Increase lane width
46-69	Add left turn phasing
23-48	Add left turn phasing
5-56	Additional lane
51.81	Additional lane
30-80	Modified traffic signal
62.64	Increase lane width
35.85	Increase the number of lanes
54.37	Increase lane width
51.81	Increase the number of lanes

3.2. Objectives

The study's objective is to assess safety at signalized intersections by simulating conflicts between vehicles and then suggesting suitable countermeasures to reduce traffic conflicts in order to enhance safety, using a simulation method by link VISSIM simulation software by Surrogate Safety Assessment (SSAM). Intersections selected were placed at the main entrances in the city of Al-Diwaniya, so these intersections were chosen to evaluate the reality of the intersections in terms of safety by determining the traffic conflicts between vehicles by conducting simulations of these intersections through the VISSIM software then creating a trajectory file and linking it to the SSAM software that evaluates safety at intersections by calculating the number of traffic conflicts between vehicles and the next stage represents the provision of appropriate countermeasures to reduce traffic conflicts to improve safety.

3.3. Characteristics of intersections

There are several characteristics of the intersections that affect the safety that should be defined for the purpose of conducting simulation in the VISSIM software. Simulation model for the evaluation accuracy and then evaluate the safety of the intersections using the SSAM software to suggest countermeasures to improve the intersections.

Some of the characteristics related to the studied intersections are as follows.

1. All selected four-legged intersections are located within an urban area of the city.
2. All approaches to intersections are of the same level.
3. Pedestrian crossing areas are not specified, in spite of the occurrence of a high proportion of pedestrians at intersections.
4. All intersections operate a fixed traffic signal for all phases during the day.

3.4. Data collection

The required data should be sufficient and highly detailed to present a more realistic picture and find more accurate results because it is considered important as input to the VISSIM program to create a trajectory file for the simulation.

The required data consists of four stages as follows:

Stage 1: Traffic data
Stage 2: Geometric characteristics data
Stage 3: Traffic conflict data
Stage 4: Data calibration

3.5. Calibration of VISSIM software

Calibration is the action that involves changing various parameters until the model accurately replicates the real-world conditions. Throughout calibration, VISSIM's parameters are changed to reflect the behavior of the networks that are formed there in order to make the model accurate. According to the characteristics they have, many different calibration parameters that can be adjusted and changed are divided into categories. It takes a lot of effort to manually calibrate VISSIM by changing all the important parameters and modeling the model to obtain the gaps between the real-world and simulated measurements. To understand the degree of calibration that is required. Driving behavior parameters consist of default values that allow users to change their scope in line with the conditions of the site to be studied. Since the drivers' behavior differs greatly from one geographical location to another, therefore, the default values for driving behavior parameters seldom match the domestic traffic characteristics and conditions of traffic for a specific zone, employed queue length and travel time for the calibration measurements, comparing the differences between the actual and modeled values.

4. Validation

The calibrated models are validated with new data established under untested conditions, involving traffic compositions, input volumes, and necessary data. The Geoffrey E. Heaver GEH statistic is used for comparing actual traffic volume with simulation data. As a basic common principle for calibration and validation, GEH Less than 5 values indicate an acceptable. For confirmation, several simulations with varied parameters are done. Table 3 reveals that at the Al-Oruba intersection, the microscopic model's GEH value is 18.888 before calibration, while Table 4 reveals that the GEH value is 2.62 after calibration indicating that it is adequately calibrated and accurately depicts the actual traffic conditions. Figure 4 also illustrates the minimum amount of difference between the actual and validated flows.

Table 3. GEH values of the Al-Oruba intersection before calibration

	Actual	Simulation	Actual-simulation difference	% Difference	GEH
NB	1444	1289	155	10.73	4.2
EB	1529	1780	-251	-16.41	6.1
SB	1503	1310	193	12.8	5.14
WB	1554	1421	133	8.55	3.448
SUM				15.67	18.888

Table 4. GEH values of the Al-Oruba intersection after calibration

Approach	Actual	Simulation	Actual-simulation difference	% Difference	GEH
NB	1444	1425	19	1.3	.5
EB	1529	1551	-22	-1.43	.56
SB	1503	1522	-19	-1.26	.488
WB	1554	1511	43	2.7	1.098
SUM				1.34	2.65

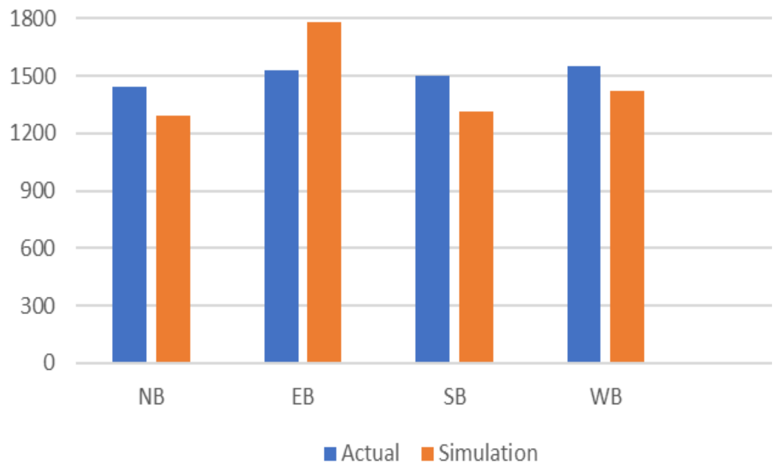


Figure 2. Difference between the number of actual vehicles and the VISSIM model at the Al-Oruba intersection before validation

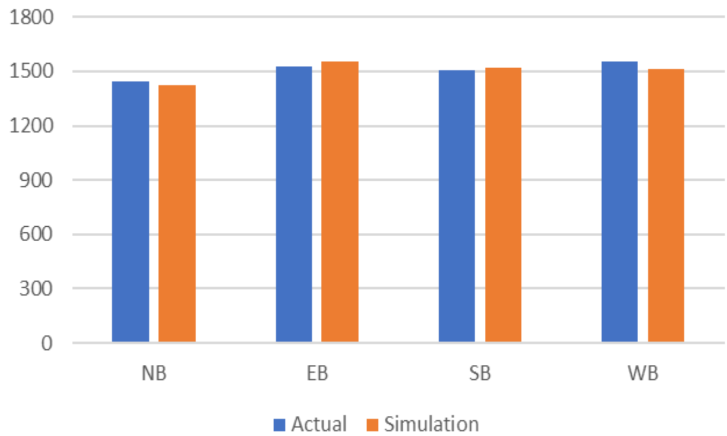


Figure 3. Difference between the number of actual vehicles and the VISSIM model at the Al-Oruba intersection after validation

4.1. Validation of observed and simulated

After confirming the success of the model calibration, the complete validity of the model to simulate the real network is confirmed. This is done by placing special counters in the model at the same points whose values were measured on-site and compared. The actual queue length at the site compared to the queue length found using the VISSIM software for profiling validation. The mean percentage error obtained was 11.6% at Al-Oruba Intersection as shown in Table 5.

Table 5. Observed and VISSIM queue length (m) at the Al-Oruba intersection after calibration

Approach	Queue Length (m)		% Errors
	Field	Simulated	
NB	140	130.45	7
EB	147	145.44	1.6
SB	135	139.15	-3
WB	127	123.85	3
		Sum % Error	11.6

4.2. Validation of observed and simulated conflicts in SSAM

The effect of the calibration procedure on the goodness of the safety assessment, the extent of the correlation between the simulation approach and the field approach and substantiate the capability of the (VISSIM & SSAM) models to produce a surrogate approach that is symmetric with the real, it requires validation of simulation has been performed by compared with observed conflict. According to the linear regression results at Al-Oruba, it is discovered that the independent variable's p-value is 0.011, showing a significant connection between the total number of simulated conflicts and the number of actual conflicts. Additionally, the model's coefficient of correlation was 0.954, which indicates that the variance in the simulated conflicts can account for 95.4% of the variation in the real-world conflicts. Table 6 displays all conflict types (crossing, lane-change, and rear end) and describes the default and calibrated simulations.

Table 6. Numbers all types of conflicts for both observed and simulated before and after calibration

Intersection	App.	C-Conflict			R-E Conflict			L-C Conflict			Total Conflicts		
		Ob.	Sia.	Sib.	Ob.	Sia.	Sib.	Ob.	Si.a	Sib.	Ob.	Si.a	Sib.
Al-Jamhori	NB	5	9	8	30	39	33	13	9	11	48	57	52
	EB	6	8	7	31	41	34	17	24	14	54	73	55
	SB	4	7	4	19	35	23	7	14	9	32	56	36
	WB	8	7	10	40	27	38	15	19	19	63	53	67
Al-Oruba	NB	7	8	8	25	42	23	9	20	16	41	70	47
	EB	9	13	9	29	36	21	9	19	15	47	68	45
	SB	11	9	12	33	47	26	18	23	20	62	79	58
	WB	9	11	10	37	51	23	14	13	18	60	75	51
Al- Fadael	NB	4	3	4	20	30	25	9	13	13	33	46	42
	EB	4	6	4	25	26	27	11	17	15	40	49	46
	SB	1	2	2	25	32	31	11	13	14	37	47	47
	WB	2	3	3	37	34	30	17	21	19	56	58	52
Al-Nesser	NB	5	7	6	41	52	47	23	25	22	75	84	69
	EB	2	3	2	20	31	20	11	14	13	35	47	33
	SB	4	3	3	36	40	41	25	19	23	67	62	65
	WB	1	2	2	18	30	20	10	17	10	32	42	29

The findings show that the calibration method reduced Mean Absolute Prevent Error (MAPE) and improved consistency between actual and simulation data.
Equation 1 is utilized for determining the results:

$$MAPE = \frac{1}{n}\sum_{i=1}^{n} \left|\frac{c_s^i - c_f^i}{c_f^i}\right| \quad (1)$$

Where: n= observation number, c_s^i= simulated traffic conflicts number at time interval i, c_f^i=the field observed conflicts number at time interval *i*

MAPE value decreased from 43% to 24% for rear-end conflicts, from 25% to 9% for the crossing conflicts, from 71.9% to 45.6% for the crossing conflicts, and from 41.9% to 10.6% for total conflicts. Table 7 shows the linear relationship between the two approaches at the Al-Oruba intersection after calibration. The observed conflicts ranged from strong with the lowest correlation coefficient (0.773) for rear-end conflicts, strong for crossing conflicts and lane change, with correlation coefficient values of 0.914 and 0.966, respectively. Total conflicts had the highest correlation (0.954) which classifies a strong correlation.

Table 7. Correlation between simulation and field conflicts at Al-Oruba intersection after calibration

Correlations		Observed	Simulated
Pearson Correlation	Observed	1.000	.977
	Simulated	.977	1.000
Sig. (1-tailed)	Observed	.	.011
	Simulated	.011	.
N	Observed	4	4
	Simulated	4	4

5. Methodology

Step 1: includes the collection of data for intersections such as engineering data, which include intersections, number of lanes, median width, traffic data including traffic volume for each approach and distribution of traffic (right, left, though, and U-turn) as well as vehicle type (heavy trucks, buses, cars) and find them from total number and traffic volume.

Step 2: includes entering the group data into the VISSIM program for the purpose of making simulations, creating a trajectory file, and linking program outputs with the SSAM (Figure 4).

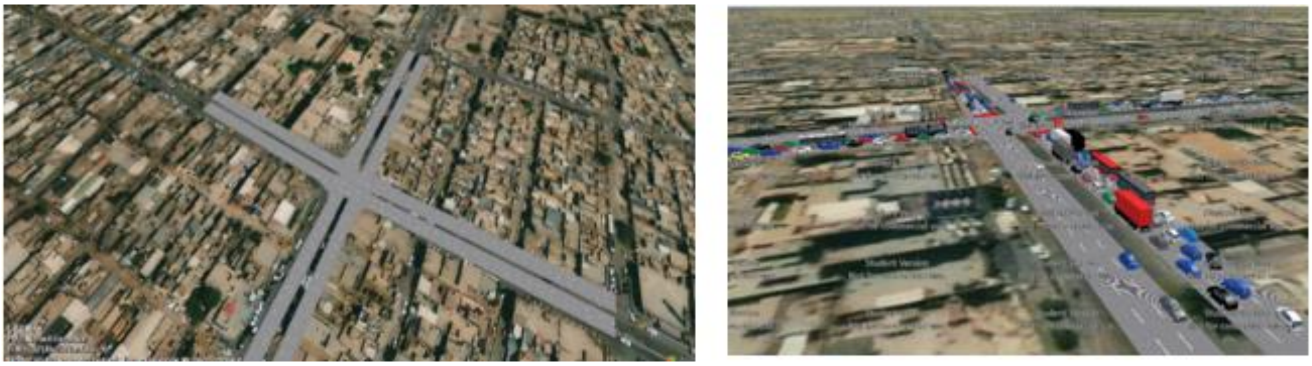
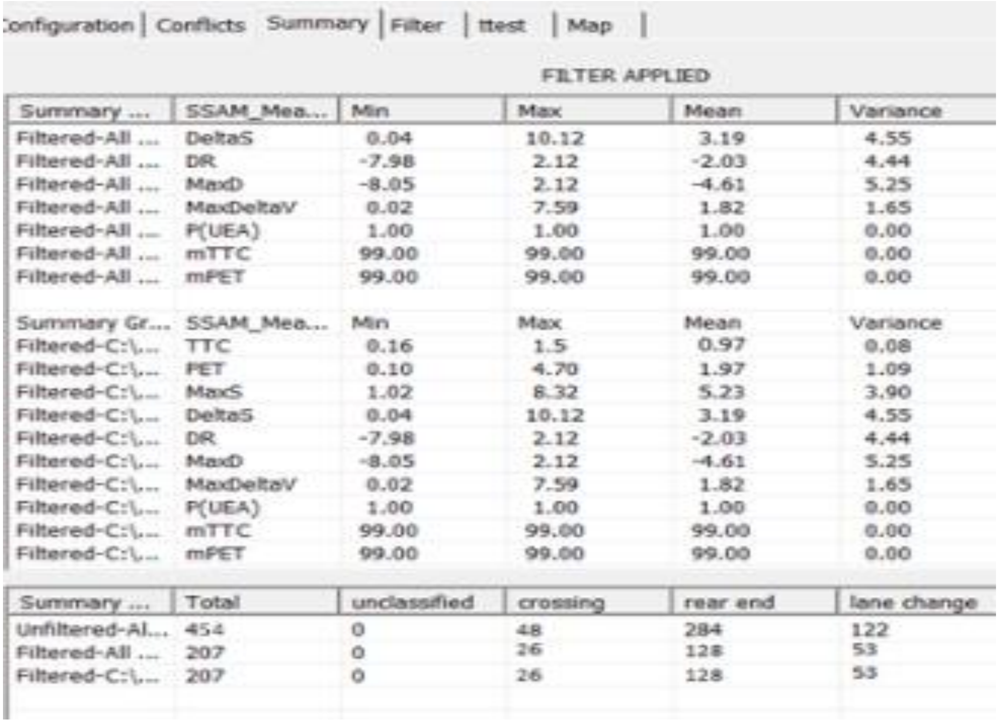


Figure 4. VISSIM simulation, creating a trajectory file at the Al-Oroba intersection

Step 3: input trajectory file for SSAM software to conduct the safety assessment by number of conflicts.
Step 4: find the number of traffic conflicts to evaluate whether the intersection is safe. Indicators of safety alternatives are found in TTC, as values TTC start from zero to five, according to Figure 5.



Summary ...	SSAM_Mea...	Min	Max	Mean	Variance
Filtered-All ...	DeltaS	0.04	10.12	3.19	4.55
Filtered-All ...	DR	-7.98	2.12	-2.03	4.44
Filtered-All ...	MaxD	-8.05	2.12	-4.61	5.25
Filtered-All ...	MaxDeltaV	0.02	7.59	1.82	1.65
Filtered-All ...	P(UEA)	1.00	1.00	1.00	0.00
Filtered-All ...	mTTC	99.00	99.00	99.00	0.00
Filtered-All ...	mPET	99.00	99.00	99.00	0.00
Summary Gr...	SSAM_Mea...	Min	Max	Mean	Variance
Filtered-C:\...	TTC	0.16	1.5	0.97	0.08
Filtered-C:\...	PET	0.10	4.70	1.97	1.09
Filtered-C:\...	MaxS	1.02	8.32	5.23	3.90
Filtered-C:\...	DeltaS	0.04	10.12	3.19	4.55
Filtered-C:\...	DR	-7.98	2.12	-2.03	4.44
Filtered-C:\...	MaxD	-8.05	2.12	-4.61	5.25
Filtered-C:\...	MaxDeltaV	0.02	7.59	1.82	1.65
Filtered-C:\...	P(UEA)	1.00	1.00	1.00	0.00
Filtered-C:\...	mTTC	99.00	99.00	99.00	0.00
Filtered-C:\...	mPET	99.00	99.00	99.00	0.00

Summary ...	Total	unclassified	crossing	rear end	lane change
Unfiltered-Al...	454	0	48	284	122
Filtered-All ...	207	0	26	128	53
Filtered-C:\...	207	0	26	128	53

Figure 5. Screenshot of the SSAM software showing the conflict values and TTC values

Step 5: includes providing suitable countermeasures of intersections to increase the safety degree at the study site by reducing conflict points and evaluation of countermeasures to ensure that these actions can increase safety degree in intersections by reducing collision points.

Table 8. Summary of countermeasures and percentage reduction for hourly traffic conflicts

Intersection	Type of countermeasures and reduction %				
	Increase lane widths	Increase the number of lanes	retiming traffic signal	Add left turn phasing	Cancel U-turn
Al-Jamhori	39.66	38.1	37.3	44.28	30.9
Al-Oruba	43.3	44.28	26.78	41.8	/
Al- Fadael	36.9	45.77	29.94	28.34	/
Al-Nesser	45.93	53.11	27.78	45	21.5

6. Results

- Al-Jumhouri and Al-Oruba intersections were classified as high-risk intersections with TTC of 0.992 and 0.98 respectively, while Al-Fadael and Al-Nesser intersections were classified as moderate-1`risk intersections with TTC of 1.025 and 1.116 respectively.
- Retiming the cycle length at the Al-Jumhouri intersection reduced the conflict points to 37.3%; the Al-Oruba and Al-Fadael intersections reduced to 26.78% and 29.94% respectively.
- Increasing the road width reduced the rates of conflict at the intersections of Al-Jumhuri, Al-Oruba, Al-Fadael, and Al-Nesser by 39.66%, 43.3%, 39%, and 45.93% respectively.
- The removal of the U-turn at the Al-Jumhouri intersection reduced the proportion of the conflict to 30.9% and TTC=1.09; the removal of the U-turn at the Al-Nesser intersection reduced the proportion of the conflict to 21.5% and the percentage of time increased is collision rate 9.36%
- Increasing the number of lanes reduces conflict rates at intersections; at Al-Jumhouri by 38.1%, while at Al-Oruba, Al-Fadael, and Al-Nesser intersections the reductions were by 44.28%, 45.77%, and 27.2% respectively.

7. Conclusions

- Before making countermeasures the severity of the conflicts at Al-Jumhouri intersection and Al-Oruba (TTC=0.992,.984 sec) respectively as a high-risk collision. The Al-Fadael intersection (TTC=1.03 sec) is classified as moderate-risk. After using the countermeasures, the severity of the conflicts at Al-Jumhouri intersection, Al-Oruba, and Al-Fadael intersection are classified as moderate risk.
- The highest percentage of reduction of traffic conflicts using the countermeasure increased number of lanes Al-Nesser intersection while using the countermeasure elimination of the U-turn is the lowest at the Al-Nesser intersection.
- The lowest percentage of traffic conflict reduction was the elimination of U-turns, where the percentage was reduced to 21.5% at the Al-Nesser intersection while the highest percentage was 53.11%, increasing the number of lanes at the Al-Nesser intersection.
- Validation has been performed comparing simulated conflict with observed conflict. According to the linear regression, the number of simulated conflicts is significantly correlated with the number of observed conflicts. In addition, the R^2 value for the model can be explained by the variation in the simulated conflicts.
- According to the validation test it was found Pearson correlation coefficient (PCC) between observed conflicts and simulated conflicts were (0.84, 0.773, 0.71, and 0.94) for rear-end conflicts, (0.71, 0.7, 0.96, 0.84) for lane changes, (0.96, 0.914, 0.85, and 0.901) and (0.97, 0.954, 0.941, 0, and 0.908) for total traffic conflicts at Al-Jumhuri, Al-Oruba, Al-Fadael, and Al-Nesser respectively.

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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References

[1] F. L. Mannering, C. Pankow, C. R. Bhat, and A. Abou, “Analytic Methods in Accident Research: Methodological Frontier and Future Directions,” 2013.
[2] A. Papadoulis, M. Quddus, and M. Imprialou, “Evaluating the safety impact of connected and autonomous vehicles on motorways,” *Accid Anal Prev*, vol. 124, pp. 12–22, Mar. 2019, doi: 10.1016/j.aap.2018.12.019.
[3] N. Nadimi, H. Behbahani, and H. R. Shahbazi, “Calibration and validation of a new time-based surrogate safety measure using fuzzy inference system,” *Journal of Traffic and Transportation Engineering (English Edition)*, vol. 3, no. 1, pp. 51–58, Feb. 2016, doi: 10.1016/j.jtte.2015.09.004.
[4] K. Gao, H. Tu, L. Sun, N. N. Sze, Z. Song, and H. Shi, “Impacts of reduced visibility under hazy weather condition on collision risk and car-following behavior: Implications for traffic control and management,” *Int J Sustain Transp*, vol. 14, no. 8, pp. 635–642, Jun. 2020, doi: 10.1080/15568318.2019.1597226.
[5] C. Johnsson, A. Laureshyn, and T. De Ceunynck, “In search of surrogate safety indicators for vulnerable road users: a review of surrogate safety indicators,” *Transp Rev*, vol. 38, no. 6, pp. 765–785, Nov. 2018, doi: 10.1080/01441647.2018.1442888.
[6] A. Laureshyn, A. Varhelyi, and A. Várhelyi, “The Swedish Traffic Conflict Technique-Observer’s manual The Swedish Traffic Conflict Technique Observer’s manual,” 2018. [Online]. Available: https://www.researchgate.net/publication/324475767
[7] S. Shelby, “Surrogate Safety Assessment Model and Validation: Final Report,” 2008.
[8] H. Kolk, E. Tomasch, M. Haberl, and M. Fellendorf, “Active safety effectiveness assessment by combination of traffic flow simulation and crash-simulation,” 2018. [Online]. Available: https://www.researchgate.net/publication/330194165
[9] D. Muley, M. Ghanim, and M. Kharbeche, “Prediction of Traffic Conflicts at Signalized Intersections using SSAM,” in *Procedia Computer Science*, Elsevier B.V., 2018, pp. 255–262. doi: 10.1016/j.procs.2018.04.037.

[10] T. A. Binjammaz, A. H. Al-Bayatti, and A. H. Al-Hargan, “Context-aware GPS integrity monitoring for intelligent transport systems,” *Journal of Traffic and Transportation Engineering (English Edition)*, vol. 3, no. 1, pp. 1–15, Feb. 2016, doi: 10.1016/j.jtte.2015.09.002.